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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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TITLE OF THE INVENTION (500 characters max)

Methods and Apparatus for Multi-carrier Communications with Variable Channel Bandwidth

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Respectfully submitted,

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Methods and Apparatus for Multi-Carrier Communications with Variable Channel Bandwidth

Xiaodong Li, Titus Lo, Kemin Li, and Haiming Huang

1 Background of the Invention

A broadband wireless communication device should be able to roam from one geographic region to another over the world. However, wireless communication spectra are heavily regulated and controlled by individual countries or regional authorities. It is inevitable that each country or region will have its own spectral band for broadband wireless communications that is different in frequency and bandwidth from others. Furthermore, even within a country or region, a wireless operator may own and operate on a broadband spectrum that is different in frequency and bandwidth from other operators. The difference in bandwidth presents a unique challenge in designing a broadband wireless communication system with flexibility that works for different bandwidths.

One of the advantages of a multi-carrier communication system is that it can be designed with a certain degree of flexibility. In a multi-carrier communication system such as multi-carrier code division multiple access (MC-CDMA) and orthogonal frequency division multiple access (OFDMA), information data are multiplexed on subcarriers that are mutually orthogonal in the frequency domain. The design flexibility lies in the manipulablility of the parameters, such as the number of subcarriers and the sampling frequency. For example, by using a different sampling frequency a DVB-T device is capable of receiving signals broadcasted from a DVB-T station that is operating on a 6-, 7-, or 8-MHz bandwidth.

The present invention is intended to provide a practical and feasible solution for multi-carrier communication with variable channel bandwidth.

2 Summary of the Invention

This invention describes the methods and apparatus for multi-carrier communication with variable channel bandwidth. The multi-carrier system mentioned in this invention can be of any special formats such as Orthogonal Frequency Division Multiplexing (OFDM), Orthogonal Frequency Division Multiple Access (OFDMA), or Multi-Carrier Code Division Multiple Access (MC-CDMA). The invention can be applied to either Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD). Without lost of generality, OFDMA is taken as an example to illustrate the present invention.

In accordance with aspects of certain embodiments of the variable bandwidth OFDMA (VB-OFDMA) system, the time frame structure and the OFDM symbol structure of the communication interface is maintained the same for different channel bandwidth. The variable channel bandwidth is realized by adjusting the number of usable subcarriers.

In accordance with yet other embodiments of the VB-OFDMA system, a core band (CB) is defined and reserved for the primary state of radio operation, where critical, essential, and important radio control signals, along with some data, are transmitted within the CB. The full-bandwidth is used for normal radio operation.

In accordance with aspects of the VB-OFDM system, automatic bandwidth recognition (ABR) enables a receiver to automatically recognize the operating bandwidth when it enters in to an operating environment or service area of a particular frequency and channel bandwidth.

In accordance with other embodiments of the VB-OFDMA system, preambles are constructed either using a direct sequence in the time domain or using an OFDM symbol which corresponds to a particular pattern in the frequency domain. The preambles occupy either the entire band or only the core band.

In accordance with yet other embodiments of the VB-OFDMA system, multi-modes are devised to handle an exceptionally wide range of variation in bandwidth.

3 Brief Description of the Drawings

The present invention will be thoroughly understood from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

Figure 1: The radio resource is divided into small units in both the frequency and time domains: subchannels and time slots. Subchannels are formed by subcarriers. The basic structure of a multi-carrier signal in the time domain is made up of time slots.

Figure 2: The relationship is shown between the sampling frequency, the channel bandwidth, and the usable subcarriers. For a given bandwidth of a spectral band or channel (B_{ch}), the number of usable subcarriers is finite and limited, whose value depends on the size of the FFT and the sampling frequency (f_s).

Figure 3: The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Data subcarriers can be grouped into subchannels in a particular way. Each subchannel may be set at a different power level.

Figure 4: The basic structure of a multi-carrier signal in the time domain is generally made up of time frames, time slots, and OFDM symbols. A frame consists of a number of time slots, whereas each time slot is comprised of one or more OFDM symbols. The OFDM

time domain waveform is generated by applying the inverse-fast-Fourier-transform (IFFT) to the OFDM signals in the frequency domain. A copy of the last portion of the time waveform, known as the cyclic prefix (CP), is inserted at the beginning of the waveform itself to form the OFDM symbol.

Figure 5: A cellular wireless network is comprised of a plurality of cells, in each of which the coverage is provided by a base station (BS). Within each coverage area, there are distributed mobile stations. A base station is connected to the backbone of the network via a dedicated link and also provides radio links to the mobile stations within its coverage.

Figure 6: The variable channel bandwidth is realized by adjusting the number of usable subcarriers, whose spacing is set constant. In this realization, a particular number of usable subcarriers constitute a channel with a certain bandwidth. The width of the core band is less than the smallest channel bandwidth.

Figure 7: A time-domain windowing function can be applied to the OFDM symbols to shape the spectrum to conform to a given spectral mask. This process is independent of the operating bandwidth.

Figure 8: A preamble is designed to occupy either the entire operating bandwidth or only the core band.

Figure 9: The entire range (e.g., from 5 Mhz to 40 MHz) of bandwidth variation is divided into smaller trunks (e.g., 5-10 MHz, 10-20 MHz, 20-40 MHz, in sizes). Each trunk is handled in one particular mode. The mode for the lowest range of bandwidth is labeled as the fundamental mode and other modes are called higher modes (Mode 1, Mode 2, etc.).

4 Detailed Description

4.1 Multi-Carrier Signal Format

The physical media resource (e.g., radio or cable) in a multi-carrier communication system can be divided in both the frequency and time domains, as depicted in Figure 1. This canonical division provides a high flexibility and fine granularity for resource sharing.

The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. For a given bandwidth of a spectral band or channel (B_{ch}), the number of usable subcarriers is finite and limited, whose value depends on the size of the FFT and the sampling frequency (f_s) and the effective bandwidth (B_{eff}), as depicted in Figure 2. There are three types of subcarriers, as illustrated in Figure 3.

1. Data subcarriers, which carries information data;

2. Pilot subcarriers, whose phases and amplitudes are predetermined and made known to all receivers and which are used for assisting system functions such as estimation of system parameters; and

3. Silent subcarriers, which have no energy and are used for guard bands and DC carrier.

The data subcarriers can be arranged into groups called subchannels to support scalability and multiple-access. The subcarriers forming one subchannel may or may not be adjacent to each other. Each user may use some or all of the subchannels. A subchannel formed by the contiguous subcarriers is called a congregated (or clustered) subchannel. A congregated subchannel may have a different power level from others.

The basic structure of a multi-carrier signal in the time domain is generally made up of time frames, time slots, and OFDM symbols, as depicted in Figure 4. A frame consists of a number of time slots, whereas each time slot is comprised of one or more OFDM symbols. The OFDM time domain waveform is generated by applying the inverse-fast-Fourier-transform (IFFT) to the OFDM signals in the frequency domain. A copy of the last portion of the time waveform, known as the cyclic prefix (CP), is inserted in the beginning of the waveform itself to form the OFDM symbol.

The downlink transmission in each frame begins with a downlink preamble, which can be the first one or more OFDM symbols in the first DL slot. The DL preamble is used a base station to broadcast signals for radio network information such as synchronization and cell identification.

Similarly, uplink transmission can begin with a uplink preamble, which can be the first one or more OFDM symbols in the first UL slot. The UL preamble is used by mobile stations to carry out the functions such as initial ranging during power up and handoff, periodic ranging, and bandwidth request, channel sounding to assist downlink scheduling or advanced antenna technologies, and other radio functions.

4.2 Cellular Wireless Networks

In a cellular wireless network, the geographical region to be serviced by the network is normally divided into smaller areas called cells. In each cell the coverage is provided by a base station. Thus, this type of structure is normally referred to as the cellular structure (Figure 5). Within each coverage area, there are located mobile stations to be used as an interface between the users and the network. A base station is connected to the backbone of the network, usually by a dedicated link. A base station also serves as a focal point to distribute information to and collect information from its mobile stations by radio signals.

In a wireless network, there are a number of base stations, each of which provides coverage to its designated area, normally called a cell. If a cell is divided in to sectors, from system engineering point of view each sector can be considered as a cell. In this context, the terms "cell" and "sector" are interchangeable.

4.3 Variable Bandwidth OFDMA

In accordance with aspects of certain embodiments of VB-OFDMA, the spacing between adjacent subcarriers is set constant and the variable channel bandwidth is realized by adjusting the number of usable subcarriers. In other words, the same OFDM symbol structure is used and the ratio between the sampling frequency and the number of FFT/IFFT is kept constant. In such a realization, a specific number of usable subcarriers constitute a channel of a certain bandwidth. For example, in Figure 6 is illustrated the signal structure in the frequency domain for a communication system with parameters specified in Table 1. The numbers of usable subcarriers are determined based on the assumption that effective bandwidth is 90% of the channel bandwidth.

Table 1 System parameters

Sampling freq.	11.52 MHz			
FFT size	1024 points			
Subcarrier spacing	11.25 kHz			
Channel bandwidth	10 MHz	8 MHz	6 MHz	5 MHz
# of usable subcarriers	800	640	480	400

In this realization, using the invariant OFDM symbol structure allows the use of the same design parameters for signal manipulation in the time-domain for a variable bandwidth. For example, in an embodiment depicted in Figure 7, a particular windowing design is employed to shape the spectrum to conform to a given spectral mask.

4.4 Radio Operation via Core Band

Radio control and operation signaling is realized through the use of a core band (CB). A core band, centered at the operating center frequency, is defined as the frequency segment that must be less than or equal to the smallest operating channel bandwidth among all the possible spectral bands that the receiver is designed to operate. For example, for a system that is intended to work at 5-, 6-, 8-, and 10-Mhz, the width of its CB can be set to be 4 MHz, as shown in Figure 6. The rest of the bandwidth is called sideband (SB).

In one embodiment, critical, essential, and important radio control signals such as preambles, ranging signals, bandwidth request, bandwidth allocation, etc. are transmitted within the CB. In addition to the essential control channels, a set of data channels and their related dedicated control channels are placed within the CB. This ensures the basic radio operation to be maintained with the use of the CB. Such a basic operation constitutes the primary state of operation. When entering into the network, a mobile station starts with the primary state and

transits to the normal full-bandwidth operation to include the sidebands for additional data and radio control channels.

In accordance with the embodiments of this invention, a preamble occupies only the CB, called the essential preamble (EP), as depicted in Figure 8. The EP alone will be necessary and sufficient for the basic radio operation. The EP can either be a direct sequence in the time domain with its frequency response confined within the CB, or be an OFDM symbol corresponding to a particular pattern in the frequency domain within the CB. In either case, the EP sequences must possess the following desired properties:

1. The autocorrelation of an EP sequence must exhibit a relatively large ratio between its correlation peak and sidelobe level.
2. The cross-correlation coefficient between two different EP sequences must be significantly small with respect to the power of the EP sequences.
3. The peak-to-average ratio of an EP sequence must be relatively small.
4. The number of EP sequences that exhibit the above three properties must be relatively large.

In an embodiment, the auxiliary preamble (AP), which occupies the SB, can be added (appended in the frequency domain or superimposed in the time domain) to the EP to form a full-bandwidth preamble (FP). The FP sequences must possess the following desired properties.

1. The autocorrelation of an FP sequence must exhibit a relatively large ratio between its correlation peak and sidelobe level.
2. The cross-correlation coefficient between two different FP sequences must be significantly small with respect to the power of the FP sequences.
3. The peak-to-average ratio of an FP sequence must be relatively small.
4. The number of FP sequences that exhibit the above three properties must be relatively large.

In yet another embodiment, the formation of an FP by adding an AP must allow the operation where a base station broadcasts the FP and a mobile station use its corresponding EP to access this base station. Consequently, The FP sequences must possess the following desired properties:

1. The correlation of an FP sequence and its corresponding EP must exhibit a relatively large ratio between its correlation peak and sidelobe level.
2. The cross-correlation coefficient between an FP sequence and any EP sequence other than its corresponding one must be significantly small with respect to its power.
3. The peak-to-average ratio of an FP sequence must be relatively small.

4. The number of FP sequences that exhibit the above three properties must be relatively large.

4.5 Automatic Bandwidth Recognition (ABR)

The VB-OFDMA receiver is capable of automatically recognizing the operating bandwidth when it enters in an operating environment or service area of a particular frequency and channel bandwidth. The bandwidth information can be disseminated in a variety of forms to enable ABR. A number of embodiments in accordance with the principles of the present invention are provided below.

4.5.1 Based on Center Frequency

In one embodiment, a mobile station, when entering in an environment or area that supports the VB operation or services, will scan the spectral bands of different center frequencies. If it detects the presence of a signal, by using envelope detection, received signal strength indicator (RSSI), or other detection methods, in a spectral band of a particular center frequency, it can determine the operating channel bandwidth by bandwidth-center frequency association such as table lookup. A table such as Table 2 is stored in the receiver. Based on the center frequency that it has detected, it looks up the value of the channel bandwidth from the table.

Table 2 Center frequency and its corresponding bandwidth

Center frequency	Channel Bandwidth
2.31 GHz	10 MHz
2.56 GHz	6 MHz
2.9 G	8 MHz

4.5.2 Based on Downlink Signaling

In another embodiment, the system provides the bandwidth information via the means of downlink signaling, such as using a broadcasting channel or a preamble. When entering into a VB network, the mobile stations will scan the spectral bands of different center frequencies, in which the receiver is designed to operate. It will decode the bandwidth information contained in the broadcasting channel or preamble.

4.6 Multi-Mode VB-OFDMA

In accordance with the principles of this invention, multi-modes are devised for a VB-OFDMA system to handle an exceptionally wide range of variation in channel bandwidth. The entire

range of variation in bandwidth is divided into smaller trunks (not necessarily in equal size), each of which will be dealt with in one particular mode, as depicted in Figure 9. The mode for the lowest range of bandwidth is labeled as the fundamental mode and other modes are called higher modes (Mode 1, Mode 2, ...). The sampling frequency of the higher modes is the multiples of that of the fundamental mode. In the higher modes, the FFT size can be multiplied in accordance with the sampling frequency, thereby maintaining the time duration of the OFDM symbol structure. For example, the parameters for a case of multi-mode design are given in Table 3, Alternatively, a higher mode can also be realized by maintaining the FFT size and shortening the OFDM symbol duration accordingly. Yet another higher-mode realization is to both increase the FFT size and shorten the symbol duration accordingly. The width of the CB in a multi-mode VB-OFDMA system must be less than or equal to the smallest bandwidth in the fundamental mode.

Table 3 System parameters

	Mode 1				Fundamental-Mode			
Sampling freq.	23.04 MHz				11.52 MHz			
FFT size	2048 points				1024 points			
Subcarrier spacing	11.25 kHz							
Channel bandwidth (MHz)	20	18	15	12	10	8	6	5
# of usable subcarriers	1600	1440	1200	960	800	680	480	400

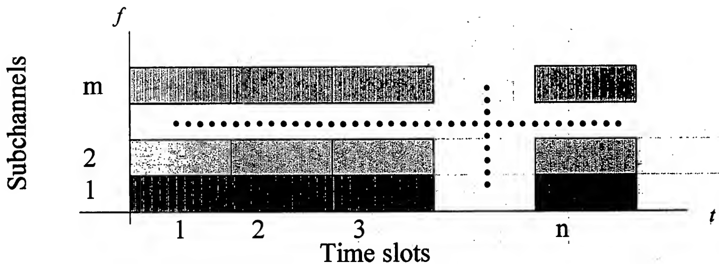
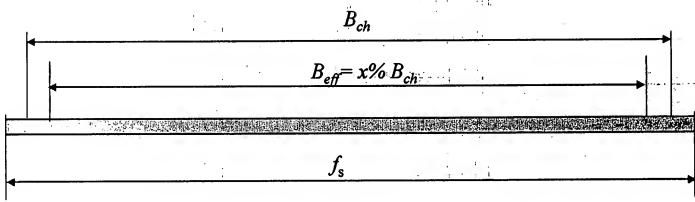


Figure 1



$$\#\text{ of usable subcarriers} = \frac{B_{eff}}{f_s} \times N_{fft}$$

Figure 2

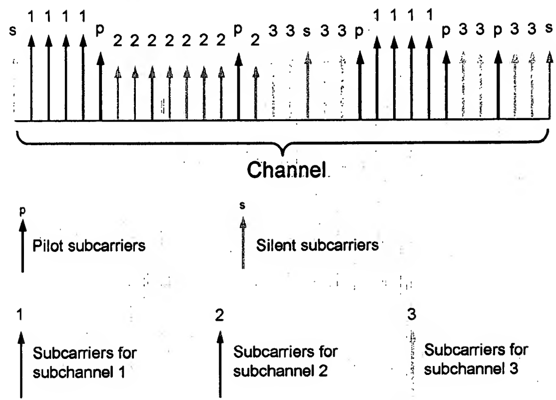

s 1 1 1 1 p 2 2 2 2 2 2 2 p 2 3 3 s 3 3 p 1 1 1 1 p 3 3 p 3 3 s
Channel
p
Pilot subcarriers
s
Silent subcarriers
1
Subcarriers for subchannel 1
2
Subcarriers for subchannel 2
3
Subcarriers for subchannel 3

Figure 3

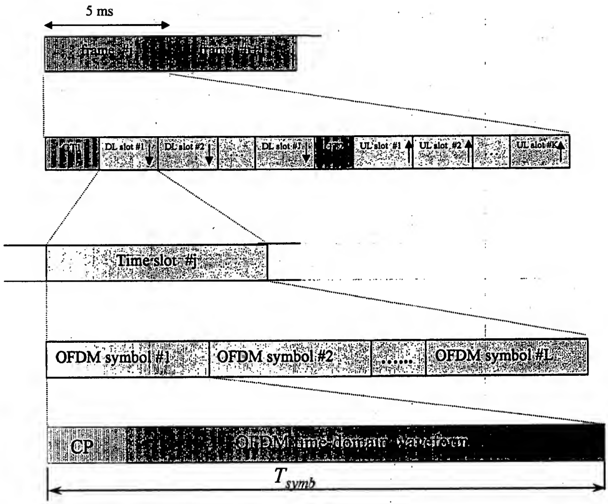

5 ms
frame #1
DL slot #1
DL slot #2
DL slot #J
UL slot #1
UL slot #2
UL slot #K
Time slot #j
OFDM symbol #1
OFDM symbol #2
......
OFDM symbol #L
CP
OFDM time-domain waveform
T_{symb}

Figure 4

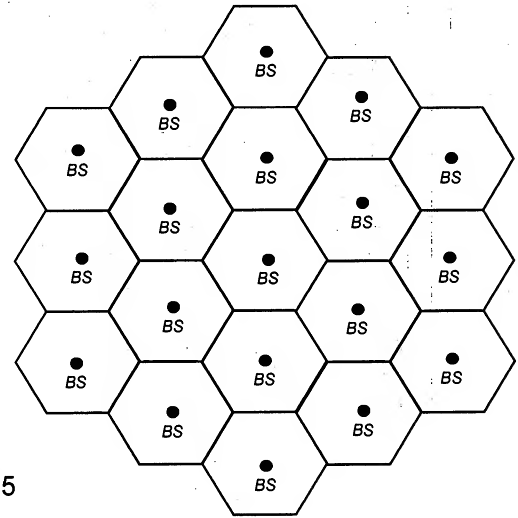
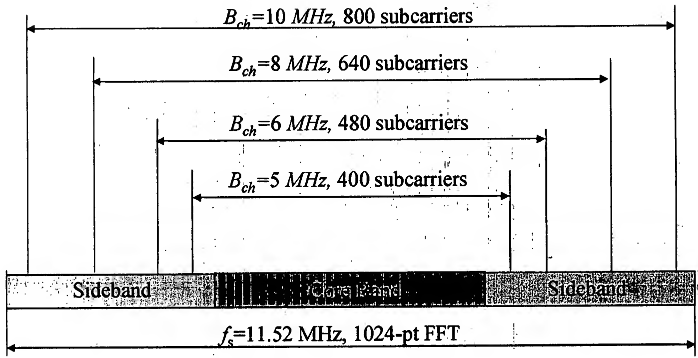


Figure 5

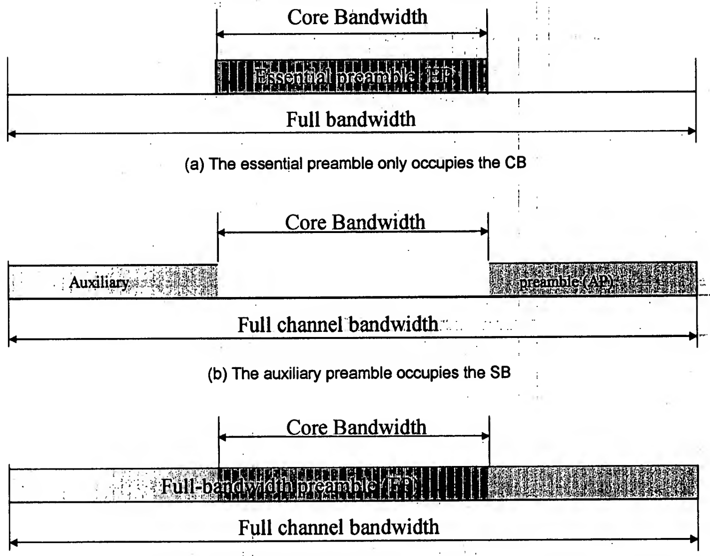


$$B_{eff} = 90\%\ B_{ch}$$

Figure 6

---- Time-domain windowing function

Figure 7



(a) The essential preamble only occupies the CB

(b) The auxiliary preamble occupies the SB

(c) The full-bandwidth preamble occupies the entire channel bandwidth

Figure 8

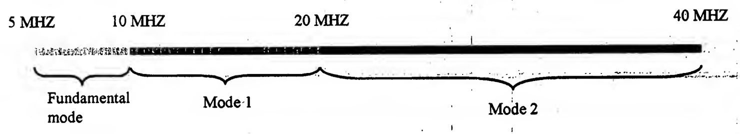


Figure 9